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WATER QUALITY MAP OF SAGINAW BAY FROM COMPUTER PROCESSING OF LANDSAT-2 DATA

John B. McKeon and Robert H. Rogers
Bendix Aerospace Systems Division
3621 South State Road
Ann Arbor, Michigan 48107

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J.B. McKeon and R.H. Rogers

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Ann Arbor, Michigan 48107

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16. Abstract

Chemical and biological water quality data collected July 31, 1975 at 16 stations within Saginaw Bay, Michigan, in concert with a LANDSAT overflight, have been processed to enable prediction of water quality in non-sampled areas. Measurements included: temperature, secchi depth, chloride, conductivity, total kjeldahl nitrogen, total phosphorous, chlorophyll a, total solids and suspended solids. When these nine water quality parameters were treated as dependent variables and LANDSAT measurements as independent variables, and processed by linear regression analysis, all parameters had correlation coefficients greater than that for the 99% level of significance. The regression equations were used to produce a five color map showing the distribution and concentration of the nine water quality parameters over the entire bay.

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Introduction

Since June of 1974 the Bendix Aerospace Systems Division has been conducting an extensive research program in the surveillance of lake eutrophication from LANDSAT. To accomplish this goal, LANDSAT data products are being generated to support the Environmental Protection Agency (EPA) modeling study of lake eutrophication in Saginaw Bay; the State of Michigan's survey of inland lakes and watersheds for the purpose of assessing the effects of watershed land use on lake water quality; and the State of Wisconsin's lake survey to determine eutrophication status, causes, effects, and control treatments. This report addresses the development of one specific map of Saginaw Bay.

The EPA sponsored study of water quality in Saginaw Bay (Lake Huron) aims to describe, on a seasonal basis, the circulation and water masses in the Bay; to monitor inputs of nutrients from its watershed; and to develop and evaluate models for predicting water quality in the Bay as a function of various control strategies (Ref. 1). A surface/subsurface measurement program, under the direction of Dr. V. Elliott Smith of the Cranbrook Institute of Science and EPA, has been underway since April 1974. From each of 61 stations distributed throughout Saginaw Bay, some 30 water quality parameters are determined on an 18-day cycle that coincides with the LANDSAT overflights.

Technique

A variety of analytical approaches have been applied to relate water quality data from Saginaw Bay to LANDSAT data (Ref. 2,3, and 4). These approaches included multiple stepwise linear regression with both ratios of band means and single band means. The procedure reported here was determined to be the most efficient and productive of the approaches investigated.

LANDSAT-2 computer compatible tapes for two consecutive scenes, acquired on 31 July 1975 (2190-15401 and 2190-15404), were processed on a Bendix MDAS (Multispectral Data Analysis System). The satellite data was first geometrically controlled by using ground control points, coastal features digitized from navigation charts. Each water quality station was called up and located on the color TV monitor. A cursor was shaped around each of the 16 stations (those sampled the same day as the LANDSAT overpass) so as to include an average of 80 pixels per station area. The mean reflectance, in raw data counts, was extracted as the independent variables and applied to a linear regression program with nine water quality parameter surface measurements (Ref. 5). (Earlier studies had indicated data from bands 4 and 5 provide the best correlation coefficients, while those from bands 6 and 7 do not contribute significantly to the regression.) The resulting regression equations (maximum count in bands is 254) are:

Regression Equations

Saginaw Bay 7/31/75 (16 Samples)

Temperature (°C)	= 9.61 + 0.007 (Band 4) + 0.572 (Band 5)
Secchi Depth (m)	= 8.24 + 0.142 (Band 4) - 0.458 (Band 5)
Chloride (mg/l)	= 9.489 - 2.040 (Band 4) + 3.202 (Band 5)
Conductivity (micromhos)	= 194.1 - 7.72 (Band 4) + 13.79 (Band 5)
Total Kjeldahl Nitrogen (mg/l)	= 0.419 - 0.102 (Band 4) + 0.153 (Band 5)
Total Phosphorus (mg/l)	= -0.0069 - 0.0033 (Band 4) + 0.0059 (Band 5)
Chlorophyll a (ug/l)	= 0.908 - 1.02 (Band 4) + 1.67 (Band 5)
Total Solids (mg/l)	= 154.1 - 7.73 (Band 4) + 12.93 (Band 5)
Suspended Solids (mg/l)	= 41.04 - 8.32 (Band 4) + 11.57 (Band 5)

The correlation coefficients ranged from .73 for Secchi Depth to .94 for Temperature, Nitrogen, and Phosphorus. In all nine cases the level of significance was at $P < .001$.

Next, the unprocessed LANDSAT data was again displayed on the color TV monitor. The entire bay was carefully screened in a false color mode and also in level slice modes of bands 4 and 5. This effort enabled the investigator to identify five distinct water masses. After the cursor was positioned to representative areas of each mass, training areas, the mean reflectance and desired colors were entered into MDAS's multivariate categorical processor. The entire bay and part of east-central Michigan was categorized, the two scenes were "end-to-end" merged, and finally the processed data was filmed as three color separates on a drum recorder.

In order to relate the color coded map of the bay to levels of water quality the means of each of the five water masses were entered into the equations given above. The mean counts of the training areas in bands 4 and 5 respectively were; blue 30.3 and 18.9, green 36.7 and 23.5, orange 41.6 and 26.8, red 42.7 and 30.4, and magenta 45.6 and 37.8. The final color product is shown as the attached figure at the original filming scale of 1:1,000,000.

Discussion

Evaluation of the water quality map is not completed but some interesting features have already been identified.

The Saginaw River enters Saginaw Bay at its extreme southwestern end and contributes the majority of pollutants found in the Bay. The river and its tributaries drain an area of more than 16,060 km^2 that is predominantly agricultural land and contains four major urban centers. The magenta color, which

represents levels of water quality that are beyond the range of the sample data used in the regression program, enhances the plume of turbid water that enters the Bay from the Saginaw River and extends in a southeast direction. In the shallow near-shore zone (less than six feet deep) of the lower bay, the magneta denotes areas where there is significant local resuspension of sediment.

A lobe of relatively clean Lake Huron water (blue) appears to enter the mouth of the Bay between a central island (Charity Is.) and a coastal point (Lookout Pt) and flow up the Bay (south) along its deepest channel. The boundary of the lobe and the Bay water (green) is very pronounced and not gradational as is the case with the remaining three water mass boundaries.

A third feature is the spiral of water masses just northeast of the "thumb" of Michigan. This is an apparent mixing zone of turbid water that has been transported from the Bay into Lake Huron. The transporting current may have been set up by the counterclockwise deflection of southward moving Lake Huron water, along the shallow area between Charity Island and the eastern shore of the Bay mouth (Oak Pt.). Thus one mass of Lake Huron water enters the Bay along its western shore while another mass is prevented from entering but helps transport turbid bay water into Lake Huron. The apparent increase in turbidity at the top right corner of the map is due to the presence of an atmospheric haze associated with clouds, about 25 km northeast of the right corner of the map, but within the full scene.

The nine water quality parameters were mapped as one map. If separate maps were required for each parameter the breaks between color levels could be relocated so as to better proportion the levels. For example, the map shown here indicates that chlorophyll ā is low in the outer bay and central portion of the inner bay but extremely high in the near shore zone of the inner bay. A separate map, made with different training areas, could be made for each parameter. In the case of chlorophyll ā this would permit perhaps one color code for the areas of low concentration and four colors for the areas of high concentration as opposed to three and two respectively.

It should be emphasized that the equations used to relate the water quality measurements with the LANDSAT data are not necessarily applicable to LANDSAT data of a different date. Atmospheric conditions can be extremely variable with time over the Bay region.

Conclusion

Computer processing of LANDSAT digital data and water quality surface truth measurements taken on the day of the overpass provides a means of producing a synoptic map of Saginaw Bay water quality for non-sampled areas. Use of non-linear regression and work with data of different dates may help to further the goals of the EPA in their effort to study the circulation of water masses and model the water quality of Saginaw Bay.

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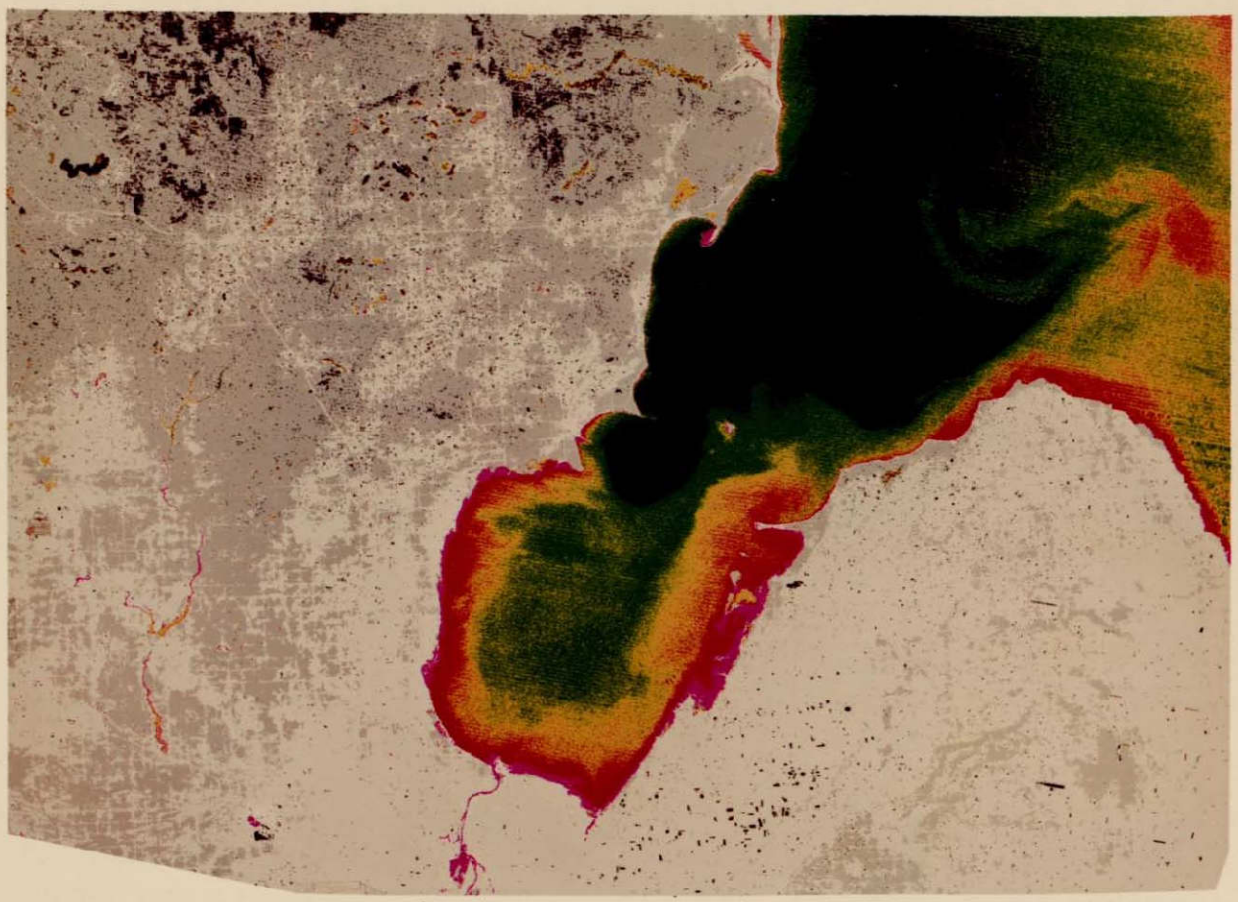
WATER QUALITY MAP
SAGINAW BAY, LAKE HURON



	Blue	Green	Orange	Red	Magenta	Standard Error of Estimate
Temperature (°C)	20.6	23.3	25.2	27.3	31.6*	1.6
Secchi Depth (m)	3.9	2.7	1.9	0.4	< 0.4*	1.1
Chloride (mg/l)	8.2	9.9	10.4	19.7	37.5*	1.9
Conductivity (micromhos)	221	235	243	284	363*	8.9
Total Keldahl Nitrogen (mg/l)	.22	.27	.28	.71	1.55*	.08
Total Phosphorus (mg/l)	.005	.012	.014	.032	.066*	.004
Chlorophyll $\overline{a}$ (ug/l)	7.6	7.6	5.0	37.5	99.1*	8.5
Total Solids (mg/l)	164	174	179	217	290*	15
Suspended Solids (mg/l)	1.6	2.7	3.2	8.1	17.6*	2.2

*These values are beyond the range of the sample data.

10 Mi

16 KM

The water quality parameter levels were determined by regression analysis of Landsat digital data (31 July 1975, 2190-15401 and 2190-15404) and surface sample data collected at 16 bay stations on the same date by the United States Environmental Protection Agency (cruise 25).

Land features are shown as white for urban and built up, light gray for agricultural and grasslands, dark gray for forests and yellow for wetlands.

Computer processed for NASA by the Bendix Aerospace Systems Division (June 1976).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